Autonomous Spacecraft Free-Flying Robots

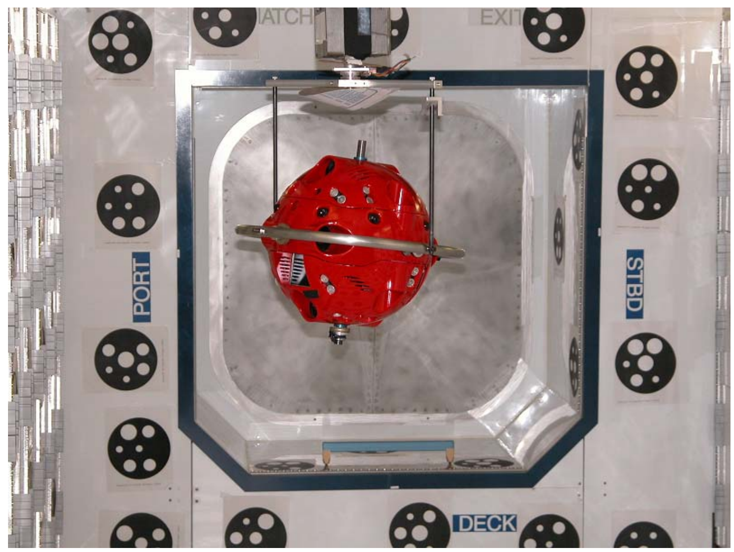
Autonomous Spacecraft Free-Flying Robots are being developed to provide flexible, close-range mobile sensing inside and outside of in-space vehicles, stations, and potential space facilities, such as fuel depots and power generation stations. This mobile remote sensing capability provides astronauts, ground personnel, and onboard spacecraft systems a data-rich virtual presence wherever it is needed for performing a variety of tasks including inspection, leak detection, damage assessment, event monitoring (e.g., docking), and in-space assembly coordination. These capabilities will reduce risk for a variety of human and robotic mission activities.

Background

To support a sustained human and robotic presence in space, it is essential that flight crews, robots, and spacecraft systems locally sense, make decisions, and act to mitigate mission risks and support new mission capabilities, such as in-space assembly and monitoring of spacecraft and facilities, e.g., an in-space depot for refueling lunar landers. Limited fixed sensors and limited flight crew availability make it difficult to sense when and where specific observations are needed. Particularly during off-nominal situations or during catastrophic events when fixed sensors fail, deploying mobile sensor probes to perform autonomous or teleoperated inspection and monitoring tasks is critically important. Even when a failure cannot be prevented or a nominal state restored, ascertaining the cause of the failure is extremely valuable. Consider how helpful having a free-flying robot would have been for the following past space missions to name a few:

- Assessing the damage after the Apollo 13 explosion.
- Inspecting the Space Shuttle Challenger tiles.
- Evaluating and monitoring the atmosphere after the MIR space station fire.
- Externally monitoring the docking of the Progress cargo spacecraft with MIR prior to the crash, which caused loss of power and significant loss of atmosphere.
- Internally monitoring the atmosphere of MIR after the Progress spacecraft collision.
- Monitoring failed spacecraft orbit insertions, e.g., Mars Observer, Mars Climate Observer.
- Inspect failed equipment deployment, e.g., Galileo spacecraft high-gain antenna.

More advanced free-flying robots can be equipped with one or more manipulators to perform assembly and maintenance tasks, as well as object retrieval when needed.



Research Overview

As part of the autonomous spacecraft free-flying robot research and development effort at the NASA Ames Research Center, a wide range of technologies are being developed and integrated to enable people, robots, and a spacecraft test facility to cooperatively achieve mission goals. These technologies include:

Machine vision for navigation, object recognition, and defect detection. As part of this effort, the project has developed a FPGA Vision Processing Unit with four stereo camera pairs that extracts features and their positions from 8 images and generates four depth maps at 15 frames per second. This enables a free-flying robot to determine its location and orientation with respect to a spacecraft within a few centimeters and a few degrees respectively.

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Declarative model-based, temporally flexible, constraint planning for high-level goal decomposition into task sequences that adhere to flight rules, resource management, and multi-agent task coordination. The project has integrated and tested the NASA Ames EUROPA planning system on the PSA, a spherical spacecraft free-flying mobile robot shown in the images on this data sheet.

3-Dimensional path planning that optimizes for various attribute combinations including distance, time, fuel, and safety.

Robust Plan Execution and Adaptive Control that executes temporally flexible plans and continually replans as new sensor information, task completion data, and commands are received. The project has integrated and tested the NASA Ames Intelligent Distributed Execution Agent (IDEA) executive on the PSA.

Integrated Vehicle Health Management including active fault detection, isolation, and recovery. The project has demonstrated how an advanced spacecraft Environmental Control and Life Support System (ECLSS) can autonomously use a free-flying mobile robot to actively diagnose and recover from a number of faults that would otherwise require flight crew and ground personnel intervention. The project has integrated and tested the NASA Ames Livingstone 2 model-based diagnosis system on the PSA/ECLSS multi-agent system. The Livingstone 2 diagnosis system derives the most likely state of the system from qualitative models of the system state over time. The system was modified to suggest sensing tasks that can be performed by a PSA to eliminate suggested diagnoses when more than one exists based on the currently sensed data.

Human-Robot Interaction including graphical user interfaces for high-level autonomous control, spoken language dialogue management, and gesture recognition.

Special-Purpose Robot Hardware, such as small, 0.5kg reaction wheels for attitude control and a 12’ x 35’ x 8’ Micro-Gravity Test Facility that detects fraction-of-an-ounce forces acting on its payload and moves the payload as if it were in micro-gravity as well as simulates other planetary gravity forces up to 1G. This test facility enables free-flying robots to operating on Earth as if they are in micro-gravity.

Relevance to Exploration Systems

This research addresses a wide range of strategic technical challenges including robust autonomy, human deep-space presence, in-space assembly, robotic networks, as well as providing flight crew and ground personnel a data-rich virtual presence. We expect the research results to impact Office of Exploration Systems mission system designs over the next decade.

H&RT Program Elements:

This research capability supports the following H&RT program /elements:

ASTP/Advanced Studies, Concepts, and Tools
ASTP/Software, Intelligent Systems & Modeling
TMP/Advanced Space Systems & Platform
TMP/Advanced Space Operations
TMP/Lunar and Planetary Surface Operations
TMP/In-Space Technology Experiments

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